G. High-Strength Steel Joining Technologies Project

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Contractor: U.S. Automotive Materials Partnership
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Objective

- Facilitate the increased use of the advanced high-strength steels (AHSSs) in the Auto/Steel Partnership (A/SP) lightweighting projects through the development of weld parameters and weld schedules that will produce quality welds in various grades of these advanced steels. Consider resistance welding as well as laser and metal inert gas (MIG) welding processes.

Approach

- Evaluate weld lobe under peel test conditions to determine the optimum welding time and current. Test for properties such as hardness, tensile shear, metallographic, impact, and fatigue.
- Evaluate weld bonding of three of the AHSSs and compare to straight welded joints.
- Evaluate properties of tensile shear, impact, and fatigue for various welding practices and weld bonded joints.
- Document fracture characteristics of resistance welds and compare to the weld strengths in the development of a standard for partial-thickness fractures.
- Perform a design of experiment (DoE) analysis of relationships of weld parameters to physical properties.
- Work in coordination with the Lightweight Front Structures Group to determine the weld parameters in welding DP-980 and DP-800 steels (various thicknesses) to make and crash a predesigned front structure (for optimum light weight).
- Determine the welding parameters to produce optimum welds and statistically test welds produced with these parameters. Tensile shear and hardness will be evaluated (complete).
- Conclude the American Iron and Steel Institute/Edison Welding Institute (AISI/EWI) tempering project that addresses the effect of tempering welds made with dual-phase, Martensitic, and transformation-induced plasticity (TRIP) steels. This AISI/EWI project is also in concert with the DOE (complete).
- Secure the various material grades in sufficient quantities to complete the resistance welding and the materials planned for laser and MIG welding (complete).

- Write the test plan and procedures for the SWSG project (Statement of Work).
- Weld coupons and test accordingly (in process).
- Report results (in process).
- Develop a Standard of Acceptance for welds with inner-facial fractures that meet the strength requirements of welds or pull the traditional nugget. Develop into a weld standard by the American Welding Society (in process).

Accomplishments

Weld Lobe Study:

- Established procedure for weld lobe study, testing, and machine characterization.
- Characterized two machines, scissor gun and C gun, regarding rigidity and weldability.
- Secured the samples for all 12 materials, 200 ft^2 of each, at Roman Engineering, Inc. Material sheared into coupons and welded for weld lobe study, tensile shear, impact, and fatigue testing.
- Completed weld lobe study on all 12 materials (Figure 1).

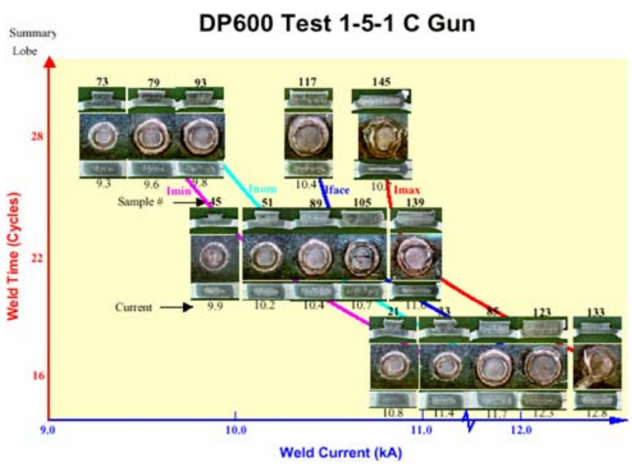

Figure 1. Sample of welding curves and welds produced. 1 of 24 weld charts.

- Completed impact tests and microhardness traverse tests on all 12 materials (Figures 2 and 3).
- Completed the design, produced, and tested fatigue test coupons (Figure 4).
- Designed, produced, and tested weld bonded coupons (Figure 5).
- Performed tensile shear tests on all material iterations (Figure 6).
- Developed acceptance criteria document and submitted same to Division 8 of American Welding Society (AWS), standards writing body of the AWS.
- Completed testing of weld study coupons (impact, tensile, and fatigue).
- Writing of final report on weld lobe study is in progress (first draft written by J. Dolfi).

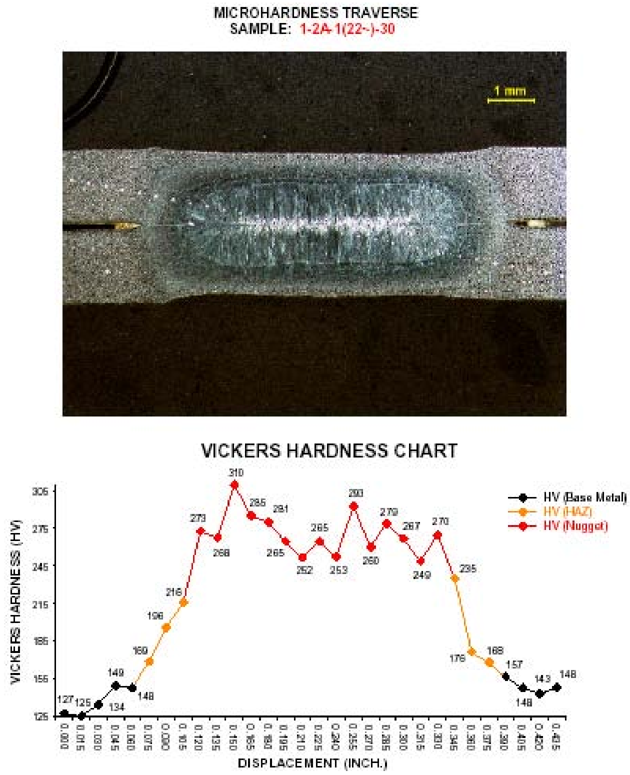

Figure 2. Photomicrograph and microhardness traverse of weld.

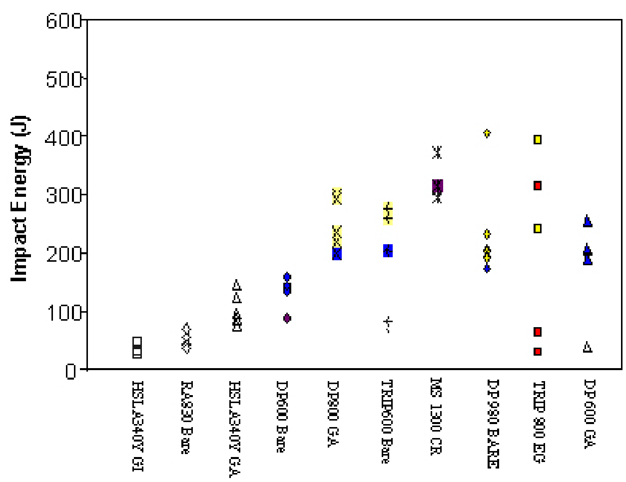

Figure 3. Impact data comparison of ten steels. Large welds and long hold time.

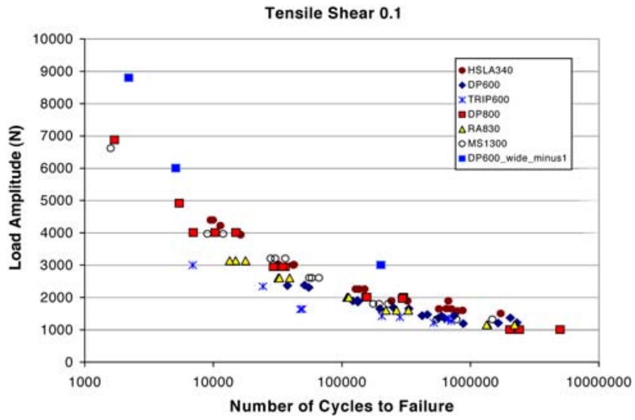

Figure 4. Load amplitude vs cycles to failure on seven materials.

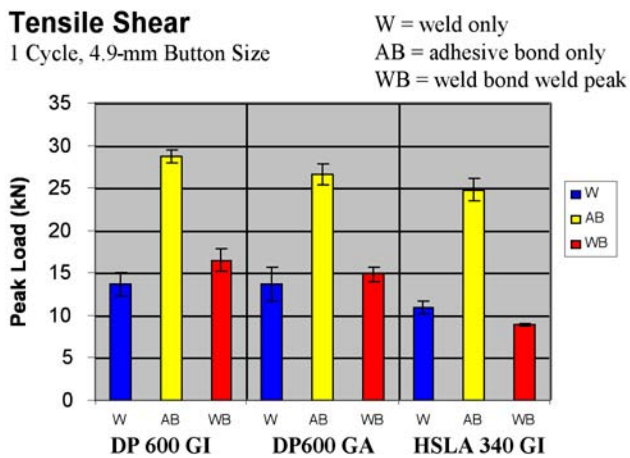

Figure 5. Tensile shear comparison of three materials: welded vs bonded vs weld bonded.

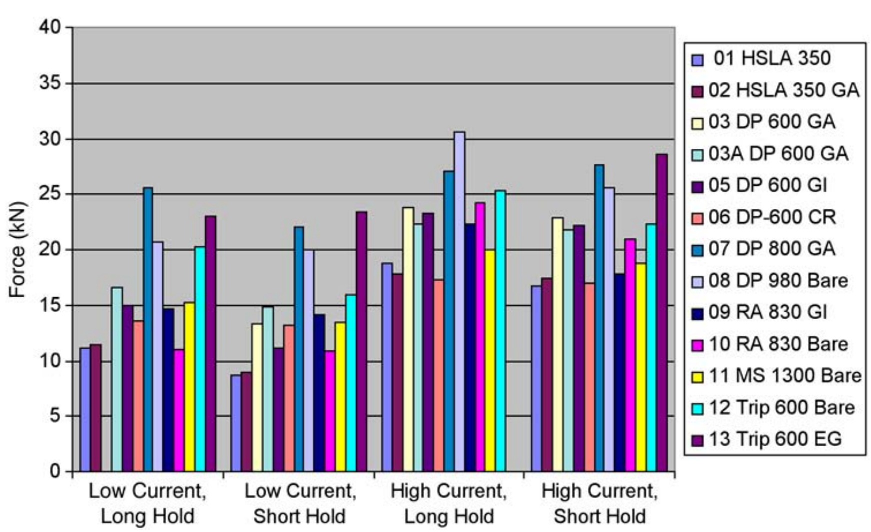

Figure 6. Tensile shear results as peak force vs weld setup for all 13 materials.

EWI/AISI Temper Study:

- Completed work on the EWI/AISI Temper Study Project. Report is published and on “A/SPsteel” Web page.

LWFS Weldability Study (resistance welding):

- Redeveloped material matrix to test DP-800 and DP-980 materials only.
- Secured materials of different thicknesses for Lightweight Front Structure (LWFS) tests.
- Tested for weld parameters for making welds with various materials.
- Supervised the welding of prototype parts for crash tests using weld parameter data.
- Built and tested two crash models via LWFS group.
- Evaluated weld performance on tested crash structures via joining team.

Structural Welding Subgroup Project (SWSG):

- Developed test matrix for MIG and laser welding of various AHSS materials.
- Secured nine test materials for testing.
- Initiated contract to weld and test according to test matrix.

Other

- Secured three AHSS materials for CanMet project. CanMet to run surface tension transfer tests on several AHSS steels at no cost.

Future Direction

- Develop a DoE analysis to determine relationships between current, hold time , electrodes, welding gun type to produce suitable properties of strength, hardness, impact, and fatigue.
- Complete testing of MIG and laser-welded joints made with HSLA baseline material and compared to Dual-Phase 600, 800, and 980 materials.
- Evaluate if a ductile/brittle transition exists by impacting joints at extremely low temperatures.
- Evaluate fractures and correlate to mechanical properties and determine the predictability of failures.
- Evaluate the weldability of projection welded fasteners to AHSSs.

Introduction

The purpose of this project is to evaluate the weldability of the new advanced high-strength steels (AHSSs) currently being considered by the automotive companies as a solution to lightweighting without compromising cost or structural strength. We are to evaluate various grades, thicknesses, and joining processes. Initially, resistance welding was evaluated, but subsequent tests extended to metal inert gas (MIG) and laser joining processes. The joining processes were to be validated by welding a front-end assembly using AHSSs, and subsequently, crash testing the assembly.

Issues that needed to be resolved in the weld lobe study before extensive welding of coupons follow:

1. weld coupon design,
2. weld tip conditioning,
3. weld gun design,
4. interfacial fractures, and
5. ultrasonic evaluation.

Weld Coupon Design

Weld coupon design was considered important because a narrow coupon (38 mm) when tensile tested, exhibited a rotational load on the weld nugget, resulting in less than optimum tensile shear strength. After discussion of a variety of ways to avoid this rotation, the coupon was designed with extra width (125 mm) and validated with comparative tests.

Weld Tip Conditioning

It was determined that an electrode stabilization procedure at 16, 22, and 28 cycles was needed to determine the weld window between no-weld and expulsion. This process was used to develop the weld lobe to meet minimum requirements (6-mm diameter).

Weld Gun Design

Two weld gun designs, one a "C" straight acting gun, and one pivot/scissor gun, with electrode movement typically used in production were used. These were characterized by gun arm deflection and overall affect on weld performance, and the nature of weld tip contact with the sheet. Tests were subsequently run with both guns for comparison.

Interfacial fractures

Sheet steels that exhibit interfacial or partial facial fractures in spot welds have been unacceptable to automotive companies for many years for various reasons (mostly because the welds with interfacial fracture usually exhibited low tensile shear strength). However, it was found by proper weld schedule, welds of this type passed all the tensile, impact, and fatigue requirements. Comparisons of the fractures with tensile, impact, and fatigue strengths, led to the construction of acceptance criteria, which eventually will lead to an industry standard.

Ultrasonic Evaluation

Consideration was given to evaluation of weld size using Ultrasonic Testing. An ultrasonic B-scanner was used to provide inspection of various welds produced using DP-600 material. Welds of various sizes were produced, including unfused internal structures. Comparisons between ultrasonic measurements and cross-sectioning measurements revealed that nugget width can be predicted to within 10% of actual width.

Peel Test

Welds were made at three cycle settings (16, 22, and 28) at various currents from no-weld to expulsion. Subsequent welds were all peel tested to fracture the welds. The calibrated peel test was determined not reliable. Welds were selected from the matrix and examined by microstructure and hardness. Sample welded coupons were made for tensile shear tests, impact tests, and fatigue tests.

Weld Conditions

All welding was performed with weld cap 4 as defined in AWS/SAE D8.9 standard. This weld cap (electrode) is fabricated from RWMA class 2 copper. It has a 45° truncated cone having a flat diameter of 7 mm and a body diameter of 19 mm. Weld force was maintained at 1500 lb. Water flow was 3.8 L/min (1 gpm), at a temperature of 81°F. Unless otherwise stated, electrode face and weld size stabilization procedures were used for all welds. Weld hold times were 30 cycles for all weld lobes.

Other Discussion—Weld Lobe Study

In the weld lobe study, all the weld data and subsequent test results were recorded on run sheets, which could be later tabulated and compared via computer program such as Minitab. Material properties such as yield and tensile, elongation, hardness, along with complete chemistries were made and tabulated also. There were 13 combinations of material, strength level, and coatings tested, all in the 1.5-mm-thickness range.

Plans are to write an executive summary similar to the attached, do a DoE on all the variables to determine their relationships, and to make available a disc of all the data for independent evaluation.

Lightweight Front Structures Work

The LFSG of the Auto/Steel Partnership needed assistance in welding a lightweight design from Dual-Phase 600, 800, and 980 materials. After obtaining the various materials, the Joining Team proceeded to evaluate the weldability of these materials, and to test weld the combinations prescribed for a front end structure. The Joining Team established the weld parameters, and assisted the prototype source in making the structure. After crash test of the front structure, the Joining Team proceeded to examine the welded assembly. Weld parameters were delivered to the Structures Team along with mechanical and chemical properties of the test materials.

EWI/AISI Temper Study Project

The EWI/AISI Temper project is one where Edison Welding and American Iron and Steel were cooperating in a project with the Department of Energy in 2002 and 2003, in an investigation using AHSSs by posttempering after welding, to produce tough welds. Since the Joining team was interested as a possible fallback position, we joined them. Edison Welding has concluded its investigation in welding and tempering dual-phase steels, TRIP steels, and martensitic steels. They concluded that tempering after welding or spike tempering during the weld cycle does reduce the hardness of the weld and improves the ductility. Quench and temper maps were produced for all the materials. A complete report is on the A/SP web site under the Joining Team reports section (www.a-sp.org).

SWSG MIG/Laser Project (Structural Welding Subgroup)

The structural welding subgroup originated out of the Joining Technologies Team in an effort to evaluate the welding of AHSSs by MIG, laser and laser-assisted MIG welding processes. Three grades of dual-phase and HSLA (baseline) materials were considered. These were materials of various thicknesses and coatings considered for frame and rail applications. All the materials for test have been secured. A test matrix was developed, and test coupons were designed. The contractor will be making and testing various combinations and reporting the results. This project should conclude by September 2005.

Low-Temperature Impact

Preliminary tests on impacting one HSS indicated a potential problem with a ductile/brittle transition at low-temperature. An investigation has been defined for low-temperature impact testing with several of the AHSSs (dual phase, martensitic, and TRIP, and using HSLA as a benchmark). The impact testing used on the weld lobe study will serve as a basis for comparison. Completion of this study is predicted by June 2005.

Several other welding issues will be addressed during 2005, guided by various members of the Team, mostly funded as in-kind.